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INTERNATIONAL ENERGY AGENCY
HYDROGEN IMPLEMENTING AGREEMENT
TASK 11: INTEGRATED SYSTEMS

Final report of Subtask A:
Case Studies of
Integrated Hydrogen Energy Systems

Chapter 3 of 11

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Chapter 3
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RENEWABLE ENERGY TEST SITE

1. PROJECT GOALS

The goal of the project was to develop a workable photovoltaic (PV) hydrogen generator suitable for use in alternative energy systems, research systems, and meteorological systems. The first phase of the project, started in May 1991, was to demonstrate a PV-hydrogen generator using Stuart Energy's ***UNICELL-CLUSTER***™ concept. ***UNICELL-CLUSTER***™, a trademark of Stuart Energy Systems Inc., refers to direct coupling of the electrolyser cells to the photovoltaic power source wherein the "current sink" current-voltage characteristic of the electrolyser is matched with the "current source" current-voltage characteristic of the photovoltaic array. The site also tested the general system design and controls needed for intermittent operation. The unit is located on the roof of Stuart Energy's manufacturing plant in Toronto, Canada (Picture 3.1) and has been operating under the full range of climatic conditions experienced at this location, where the typical annual temperature range is –25° to 35°C. The site has been used as the basis for design of scaled up versions of the system including a similar demonstration system at the University of Florida Solar Centre Cocoa Beach, Florida, USA (1993); a 3-kW photovoltaic hydrogen vehicle refueling station at the University of California Riverside, USA (1994); a 40-kW solar hydrogen plant as part of the Clean Air Now! solar hydrogen project in El Segundo, California, USA (1996); and a 5-kW solar-wind powered generator supplied to Desert Research Institute in Reno, Nevada, USA (1998). Over the past seven years, the project has also served as a test bed for various components.

Picture 3.1: Photovoltaic Array of the Renewable Energy Test Site

2. GENERAL DESCRIPTION OF PROJECT

The A.T. Stuart Renewable Energy Test Site (RETS) located at Stuart Energy Systems (SES) Inc. in Toronto has been operating since May 1991. Located on the roof of the SES factory, the system was built to demonstrate a simple low cost renewable hydrogen system (Picture 3.2). In its current configuration, a 2.45 kW (peak) PV flat panel array provides 12 V_{DC} (nominal) to an electrolyser consisting of a cell bank of six “meteorological” type electrolysis cells. The oxygen produced by the electrolysis process is vented and the hydrogen gas fills a gas holder, which supplies a small single stage air-cooled compressor. The hydrogen is compressed to 7 bar and stored in a small tank. A separate PV array charges batteries, which provide power to the control system and the compressor motor.

Picture 3.2: The Alexander T. Stuart Renewable Energy Test Site

The initial installation of the equipment was performed by the Energy Projects Group of The Electrolyser Corporation Limited, the parent company of Stuart Energy Systems Inc. The cost of the project was shared between The Electrolyser Corporation Ltd., and the Ontario Ministry of Energy under contract 600186. Funding from Natural Resources Canada under SCC Contract No. 23440-5-143/001/SQ, provided operating support for the plant over the period of 1996-1998.

3. DESCRIPTION OF THE COMPONENTS

3.1 Photovoltaic Array

The photovoltaic array is made up of fixed orientation Siemens Type M54 panels in six skids of 8 panels configured to give an output of 11.7 V at 220 A (2.5 kW). The orientation is due south at an inclination angle of 45 degrees. The latitude of the test site location is approximately 44 degrees N. Blocking diodes were removed from the panels to reduce unnecessary voltage drops. Connection to the electrolyser was made using copper bus bar.

A second PV array (420 W at 24 V) is used to a charge a bank of lead acid batteries. The battery bank is used to power the compressor and controls.

3.2 The Electrolyzer

The electrolyser, supplied by The Electrolyser Corporation Ltd., consists of 6 SM-4 meteorological cells connected in series. The peak current rating of the cells is 250 A. The cells are two-plate unipolar design with a capacity of 19 liters of electrolyte per cell.

A water seal, operating in the range of 2-8“ WC (water column), is used to maintain equal pressures in the two cells. There are no electrical controls on the electrolyzer. The cells are batch fed from a head tank located above the cells.

3.3 Gas Storage Systems

Oxygen is vented to atmosphere at the water seal. The hydrogen is collected and fed to a gas holder. The gas holder acts as an accumulator. When the gasholder fills, a trip switch turns on a single stage air-cooled oil lubricated compressor. The capacity of the compressor is 0.03 m^3/min at 0.2 kW. Power to the compressor and the controls is provided by a separate PV array. Hydrogen is stored in a tank having a capacity of 17 Nm^3 at 7 bar.

4. INTEGRATION OF COMPONENTS

4.1 Matching Components

Ideally, in matching the two systems, the voltage variation of the electrolyzer which depends on the insolation should coincide with the peak power curve of the photovoltaic power source. By adding or taking away an electrolysis cell, the coupling of electrolyzer to PV array was studied. Both under-coupled modes and over-coupled modes were investigated. In the “under-coupled“ case, the electrolyzer is current limited by the current that the array can produce for any given level of insolation. In this case, the voltage/current of the system lies to the left of the PV-array maximum power point operating curve (Figure 3.1). In the case of over-coupling, the electrolyzer is “voltage limited,“ the voltage-current curve is to the right of the maximum power point operating curve. Based on the operating experience, the highest production occurred in the over-coupled state. This is primarily due to the improved cell efficiency of the system. An over-coupled system would increase the number of cells and reduce the current density, thereby raising cell efficiency.

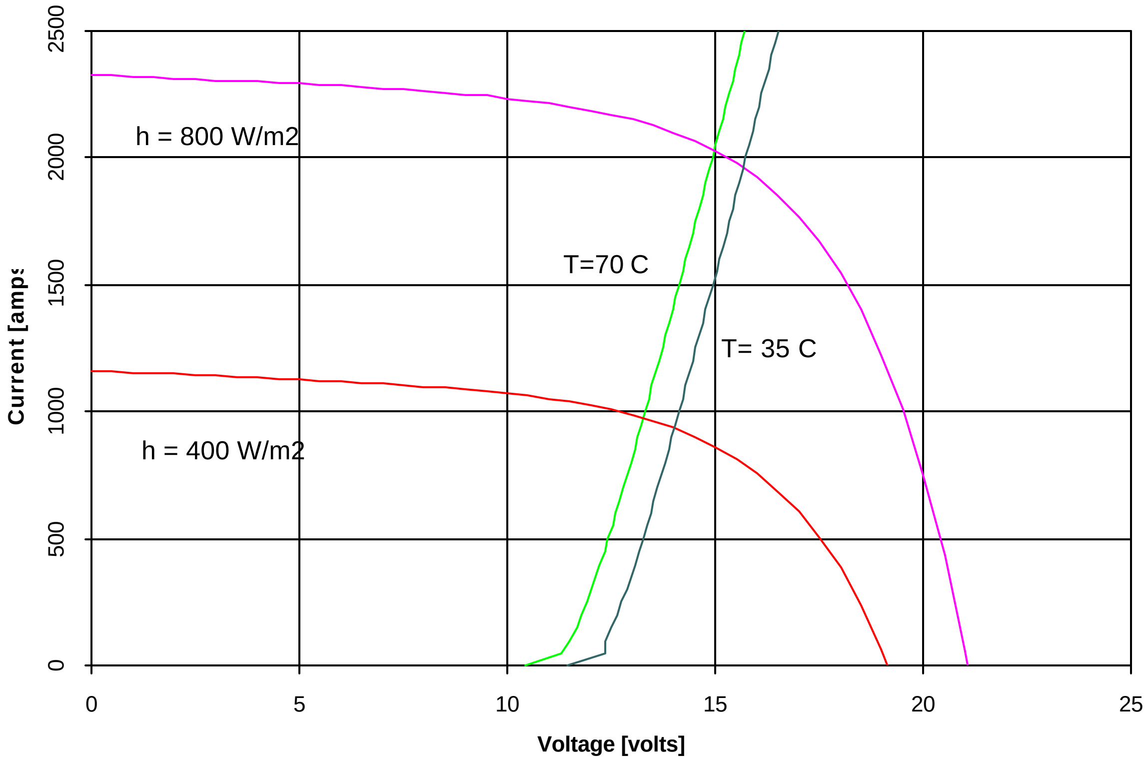

Figure 3.1: I-V Curves for PV-electrolysis integration at two values of insolation for two temperatures of the electrolyzer

4.2 Basic Schemes of Plant

The basic process elements and process flow are described in the attached drawings (Figures 3.2 and 3.3) for the gas generator and hydrogen compression system.

4.3 Plant Control

The controls of the electrolyzer are relatively straightforward and largely rely on mechanical systems. Water level control in the cells is manual, the cells having sufficient headspace to operate seven days without refilling during sunny periods. Because water additions are made directly to the cell and the concentration of KOH in the electrolyte is around 30%, the cells can operate over the temperature range experienced in Toronto, as low as –25°C.

Pressure is balanced using a water seal, which can vary between 2 and 8“ WC. The oxygen stream is vented and the hydrogen stream fills a gas holder that floats on a water bath. Limit switches on the gas bell control operation of the compressor. A check valve on the discharge of the compressor maintains a small back pressure on the compressor. When the storage tank is filled a high pressure switch stops the compressor, and the system vents through the water seal. A low-pressure switch at the inlet to the compressor insures that the pressure is positive at the suction of the compressor. The storage tank is fitted with a relief valve.

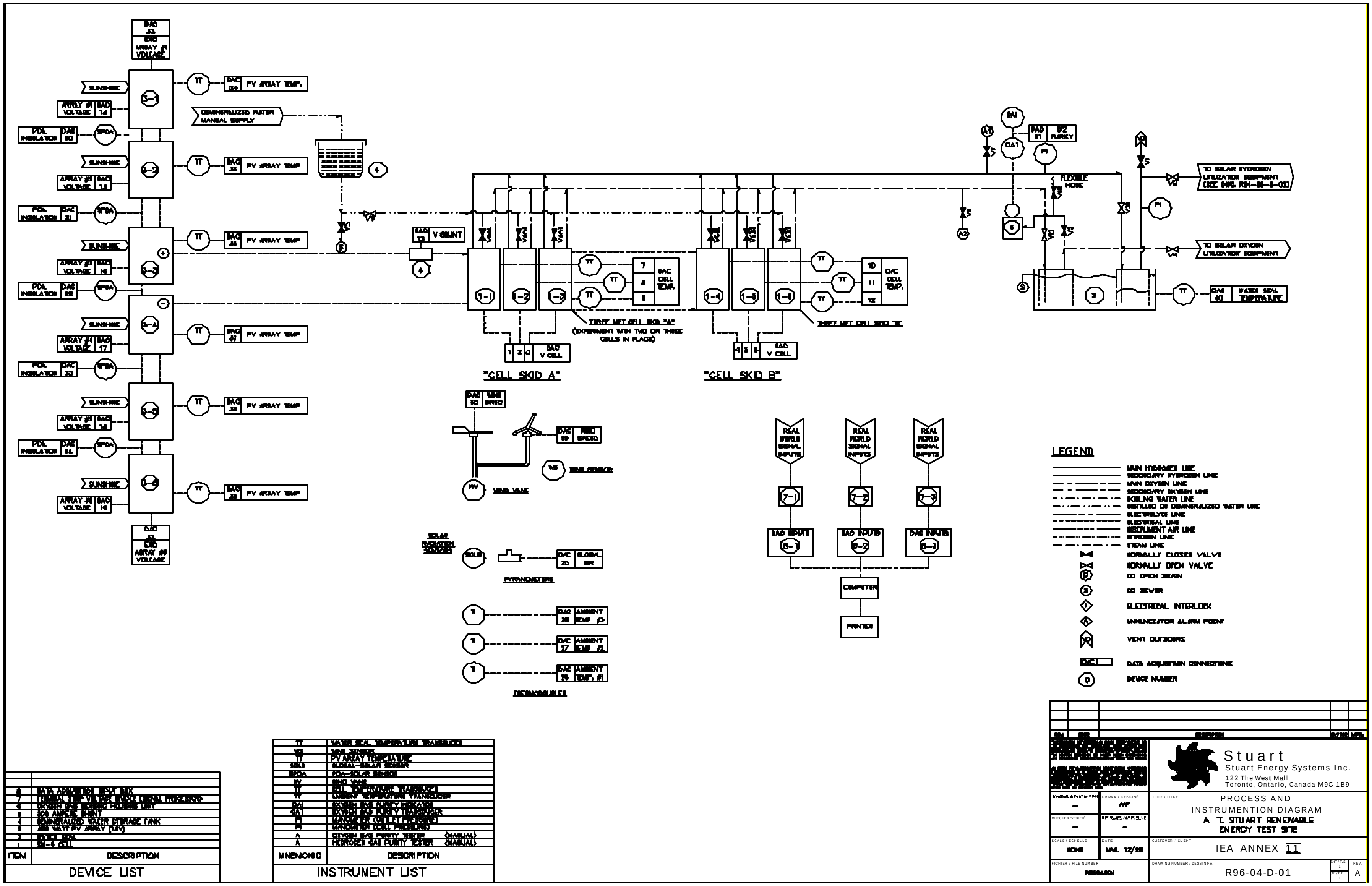

Figure 3.2: Process and Instrumentation Diagram for Hydrogen Generation Subsystem

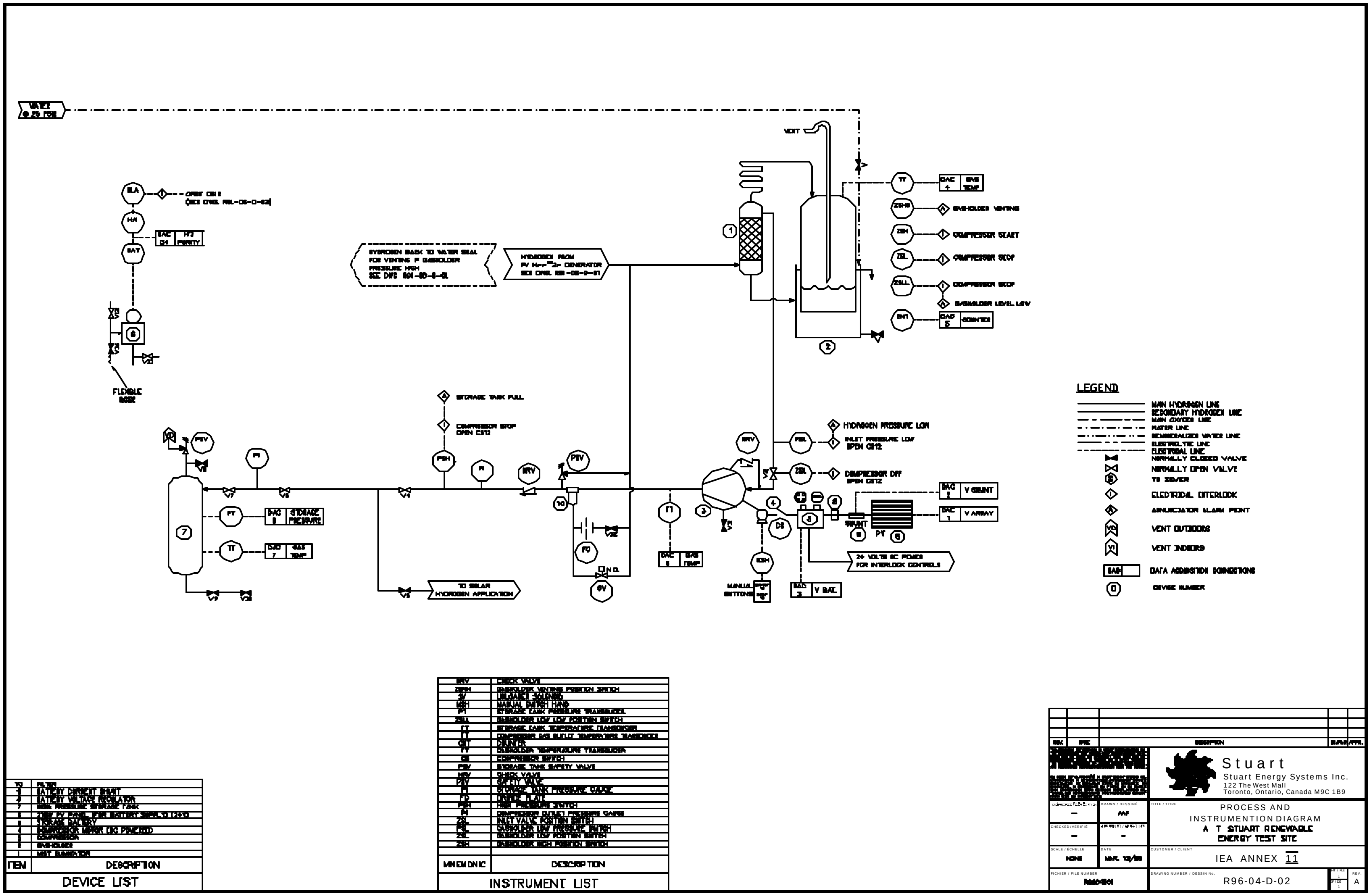

Figure 3.3: Process and Instrumentation Diagram for Hydrogen Compression and Storage

Gas purity is checked manually, once per month, using a catalyst-type gas purity sensor designed and supplied by The Electrolyser Corporation Ltd.

5. OPERATIONAL EXPERIENCE AND PERFORMANCE

Although intended to run unattended, some maintenance of RETS is required. Regular maintenance includes filling of cells with de-ionized feedwater, ensuring the water seal and gas holder are filled with water, checking for leaks, checking that the control system is operating, monitoring the pressure level at storage, and periodic checking of electrolyte concentration and gas purity.

In addition unscheduled maintenance has been required. Work performed over the period of Annex 11 (1996-1998) included:

- cleaning corrosion from the copper bus bar connecting the PV array to the electrolysis cells
- restoring electrolyte concentration in the cells
- replacing the compressor
- replacing the hydrogen inlet low pressure switch
- replacing batteries with traction type 6V.

The RETS plant is partially shut down during the winter since the compression system is not designed to operate in freezing conditions. Data were collected on all parameters even though hydrogen was not being compressed and delivered to the storage tank.

The performance of the RETS is described in various reports. A typical power/insolation curve for a summer day is shown in Figure 3.4. The power absorbed by cells (P_{cells}) follows the insolation as expected. The power discharged by batteries (P_{batt}) shows three spikes corresponding to operation of the compressor at three discrete intervals. The system efficiency from solar energy to hydrogen gas is around 7% (LHV).

6. DATA ACQUISITION

A computer controlled data acquisition system collects key operating data from RETS and displays it on a computer screen as well as stores it permanently on computer disk. The data can be imported into an Excel spreadsheet for analysis. The following parameters are measured:

- plane of array insolation
- main bus bar voltage loss
- array bus bar voltage loss
- wind speed
- single electrolyser cell voltage
- electrolyser cell bank voltage
- array current
- charging array voltage
- battery voltage
- battery current

* ambient temperature
* cell temperature
* array temperature
* compressor outlet temperature.

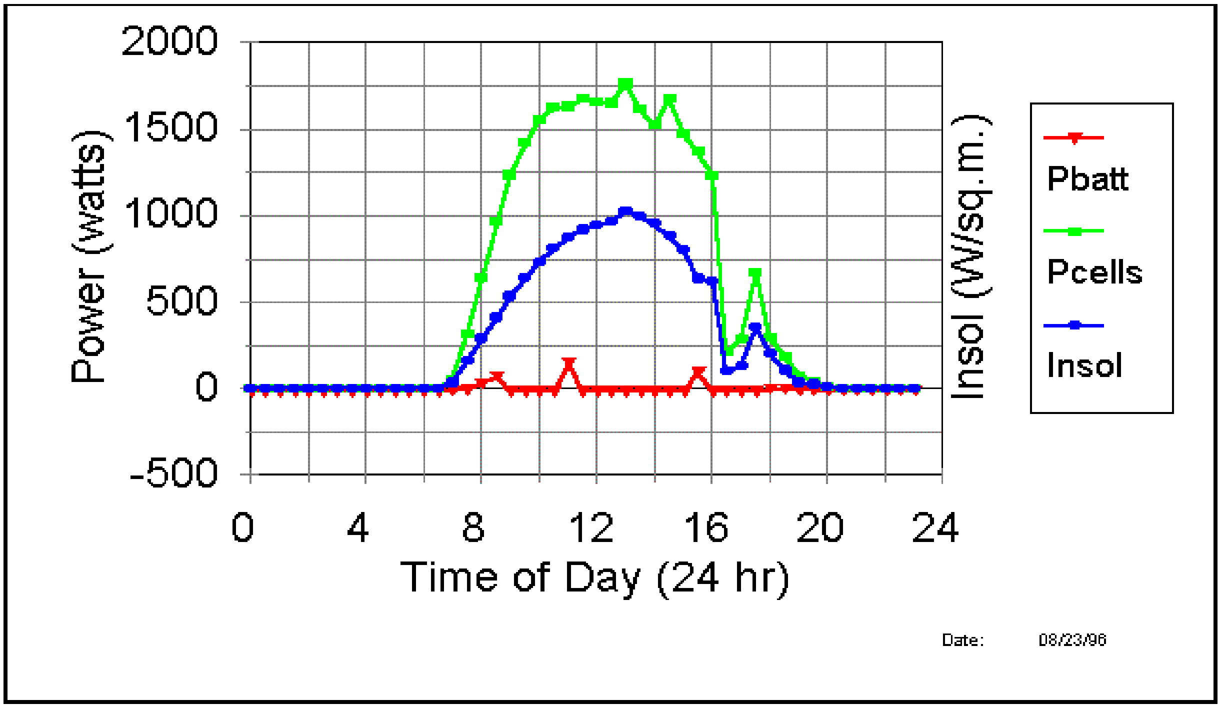

Figure 3.4: Power and Insolation Curves at RETS

The data are recorded every 10 min. Spreadsheet programs provide data analysis and presentation capabilities (see Figures 3.5 and 3.6).

7. SIMULATION

The performance of the cells and compressor were modeled with the equations in Annex 11 Subtask B. A comprehensive simulation of the entire system has not been performed.

8. ENVIRONMENTAL ISSUES

No environmental issues have arisen during this project; the only emissions are oxygen and water vapor. Essentially the unit operates as a “zero-emission“ hydrogen generator. Trace amounts of oil carryover from the compressor are collected in the storage tank and passed on to downstream applications.

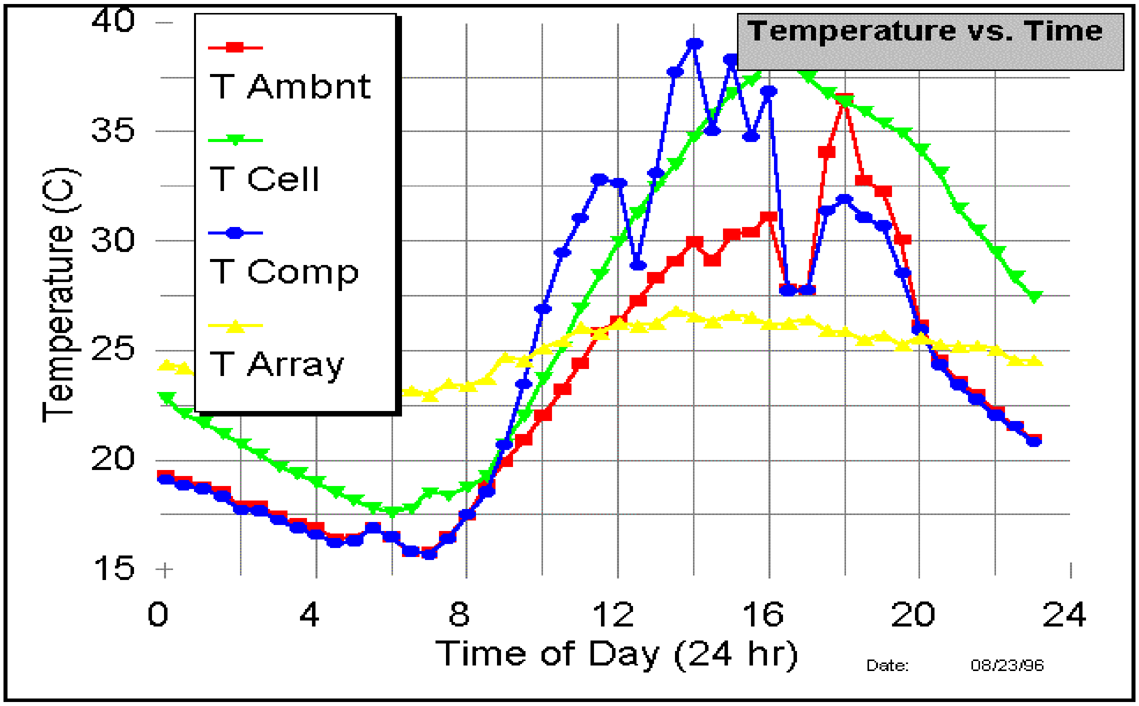

Figure 3.5: RETS Temperature Data

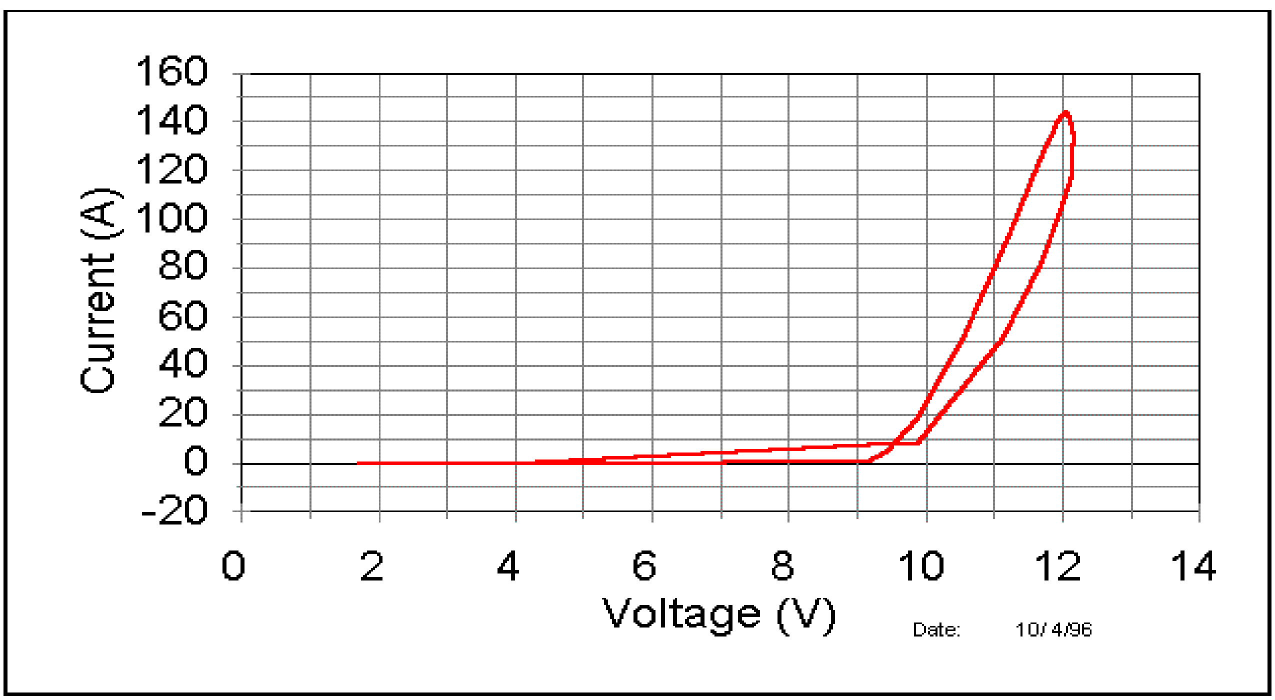

Figure 3.6: PV Array Current vs. Voltage

9. PUBLIC ACCEPTANCE AND SAFETY ISSUES

The system has been well-accepted by neighbors and is appreciated by visitors to the site. The operation of the site was approved by the Fire Branch of the Ministry of Commercial and Consumer Relations of the Province of Ontario, Canada. There have been no safety incidences reported during the seven-year period the plant has operated. Sensors for monitoring the site are not required because of the outdoor location of the equipment and the relatively small inventories of gas in the system. In general, the plant meets sound design principles for hydrogen plants: a positive pressure is maintained throughout the system, no ignition sources are permitted in areas where hydrogen may be released, and control systems prevent mixing of hydrogen and oxygen in the process.

10. OTHER EXPERIENCES

The construction and operation of this plant has provided a basis for a number of projects:

- ***UNICELL-CLUSTER***™ system at the Florida Solar Center. Similar in design to RETS.
- Riverside Solar Hydrogen Vehicle Filling station. Similar to RETS except using a four stage compressor to raise storage pressure to 345 bar.
- Clean Air Now! Solar Hydrogen Vehicle Filling Station. Using larger 5-plate Stuart cells (rated up to 4,000 A) with 15 Nm^3/h capacity, this system also uses a four-stage air-cooled compressor to compress gas to 4,200 psi.
- Solar-wind generator using a 5 kW power source. Based on the meteorological cell technology it uses a novel gas holder and water seal, which also acts as a feed water tank increasing the time interval between fills.

11. FUTURE PLANS

The current plans are to pursue the technology using the new CST (Compact Stuart) cell technology. A small wind-solar prototype is currently being tested at Stuart's Caledon Hills Test site, north of Toronto (Picture 3.3).

In pursuing commercial applications for this technology, Stuart Energy Systems is involved in a number of techno-economic studies which are examining the economic feasibility of hydrogen for energy storage to provide a continuous supply of renewable energy to small communities (Figure 3.7).

12. CONCLUSIONS

The test site has been successful in demonstrating the idea of a PV-electrolysis plant and over its seven years of operation has tested a number of different component designs. The operation of the system continues as a long-term test investigating cell life under intermittent conditions. Stuart is continuing its development of the CST cell technology and hopes to participate in the demonstration of a renewable hydrogen village energy system within the next five years.

Picture 3.3: Caledon Hills Renewable Energy Test Site

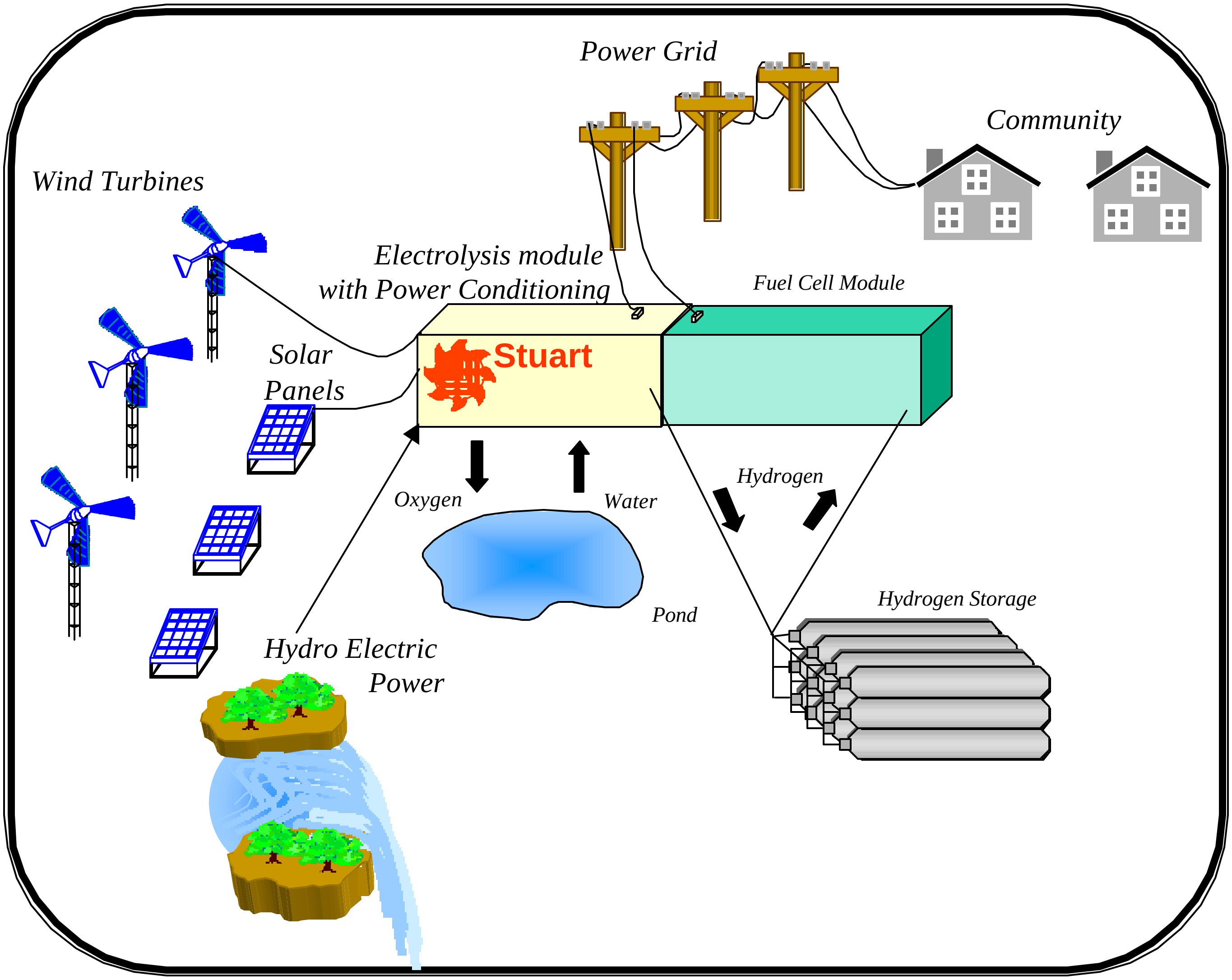

Figure 3.7: The Hydrogen Village Energy System